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HIGH INTENSITY RAINFALL AND MAJOR FLOODS IN PUERTO RICO

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HIGH INTENSITY RAINFALL AND MAJOR FLOODS IN PUERTO RICO

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INTRODUCTION

Information on rainfall intensities of short duration is particularly essential in estimating flood flows in Puerto Rico. Due to the small size of the Island, which measures approximately 100 miles long by 30 miles wide with its longer axis on an east-west direction, the watersheds contributing runoff to the streams are necessarily small, the drainage area of the three larger streams (Loiza, Arecibo and Añasco Rivers) being 330, 230, and 190 square miles respectively. The island is divided into two main north and south watersheds by its central mountain range which rises up to elevation 4000 feet and which runs approximately parallel to the longitudinal center line of the Island and at an average of some 15 miles from the South Coast. The streams, most of which run northward into the Atlantic Ocean or southward into the Caribbean sea, have very steep slopes along a large part of their length, with relatively short flat sections across the coastal plains.

These factors contribute to make the "time of concentration" of these streams - defined as the time that it takes the water to travel from the farthermost point in the watershed to any point in the stream - relatively small, the same being estimated under intense rainfalls to be, in the majority of the cases, of the order of 2 to 3 hours for the entire stream, and in the case of some of the headwater hydro-electric developments, of from 10 to 15 minutes. The need is therefore apparent for information of maximum rainfall intensities of short duration, to be used in the determination, by rational methods, of maximum flood flows to be expected from these streams.

Except for those at the Capital City of San Juan, there are no continuous records of rainfall of short duration in Puerto Rico which may be used for this purpose. Although 24-hour rainfalls have been recorded at many locations in Puerto Rico since the latter part of the nineteenth century, and at present records are available from some 325 rainfall stations throughout the Island, only a few of these have self-recording instruments from which short duration records can be obtained, and then most of the latter have been taken during relatively short periods which do not afford a reliable basis for statistical studies.

This paper presents a compilation of that rainfall information in Puerto Rico which is considered to be pertinent to the problem, and of studies made in an effort to derive, from the incomplete records available at present, a tentative pattern of rainfall which may be used as a basis for the rational determination of flood flows in Puerto Rico. Studies of the extensive records available at San Juan indicate a definite pattern and behavior of rainfall, as to intensity - duration - frequency relation, which follows the general pattern observed in the United States and is very similar to that in the state of Florida. A comparison between the 24-hour rainfalls of high intensity at San Juan,

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and 163 heavy storms recorded throughout the Island during the last 53 years, further indicates a similarity of pattern, from which an estimated intensity - duration - frequency relation for maximum rainfalls throughout the Island has been determined. This relation is represented in graph form and also equations representing the same have been developed.

Besides presenting records on normal rainfall as well as on rainfalls of high intensity in Puerto Rico, data on the distribution of rainfall throughout the Island during 3 storms - most of them during tropical hurricanes - is included in the paper. In additions, there are also included estimates of flood flows in two streams in the Island, during two of these storms, which appear to be of unusual magnitude even when compared to record breaking floods in the United States and other countries from watersheds of similar size.

The need is apparent for the installation throughout the Island of additional stations with self-recording instruments which will furnish more information on short duration rainfall intensities, to provide a check on the tentative rainfall pattern herein proposed for Puerto Rico. It would also be of interest to know how similar data recorded in neighboring countries, where similar conditions prevail, would fit in the tentative pattern proposed.

The cooperation of the U. S. Weather Bureau Office at San Juan, P.R., and of the U. S. Soil Conservation Service in furnishing rainfall data is gratefully acknowledged. The writer is indebted to Mr. R. Solivan[2] and Mr. A. Aguilar, Jr.[3] who kindly helped in the compilation of the original hydrographic records, and to Mr. William Márquez,[4] who has assisted in the assembly, analysis and presentation of the data.

General

The U. S. Weather Bureau has described rainfall in Puerto Rico as follows: "The rains, while frequently very heavy, are usually of short duration. The average duration of a shower is probably not more than ten or twelve minutes, although on many occasions a series of intermittent showers will extend over a period of an hour or two. During the passage of a tropical hurricane, or when one of the more extensive north Atlantic storms passes eastward along a more southern route than usual, the period of continuous rainfall may be extended to several hours and even throughout the day, or there may be several successive days of unsettled weather with frequent showers."[5]

Rainfall records in Puerto Rico are of a rather limited nature. Although there are records available from some 325 rainfall stations throughout the Island, only a few of these stations have self-recording instruments. The rest of the stations have observations taken once or twice daily. 207 of these stations are operated by the sugar mills and sugar cane growers and are located in clusters along the coastal plains of the Island. The other 118 stations, operated by the U. S. Weather Bureau and other Insular and Federal Government agencies, are fairly well distributed throughout the Island. Of these, 87 stations are at present under operation, 28 of which have continuous records since the year 1899 or before, and the other 59 have continuous records during shorter periods varying from 8 to 47 years.

The station with longest record is at San Juan, where monthly records were maintained since June, 1867 by the Spanish Authorities, and daily records

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3. Hydrographic Engineer, P.R.W.R.A.
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5. The Climate of Puerto Rico, by D. L. Fassig.

have been taken by the U. S. Weather Bureau since March, 1898. Continuous records with self-recording instruments have been taken at San Juan since 1905, and at a few other stations, operated by the Soil Conservation Service, for interrupted periods totalling about 10 years since their installation on or about 1937.

The average annual rainfall for the entire Island is about 76 inches. The distribution of mean annual rainfall, as determined from records compiled by the U. S. Weather Bureau and the Puerto Rico Water Resources Authority, is given on the accompanying Rainfall Map, Exhibit No. 1. There are three well defined areas of heavy rainfall, in each of which the annual amount exceeds 100 inches; the Luquillo Range, on the northeastern part of the Island; the region in the central part of the Island, near the top and on the northern slope of the Main Mountain range known as the Cordillera Central (headwaters of Arecibo River Basin); and the Mountains near the western end of the Cordillera, and in the vicinity of Las Marías and Maricao.

Maximum 24-Hour Rainfalls

Table No. 1 on page 364-12 lists in chronological order 163 heavy storms with 24-hour rainfall of six inches or more, which have been recorded at the different stations in the Island during the 52 year period since the year 1899.

The heaviest 24-hour rainfalls recorded during the different months in the Island are given in Table 2. The highest 24-hour rainfall recorded since the establishment of the Climatological Service of the U. S. Weather Bureau in 1899, occurred at Adjuntas during the "San Ciriaco" hurricane on August 8, 1899. The town of Adjuntas was in the center of the path of the hurricane, and the local observer reported a rainfall of 23 inches in 24 hours. Although this intensity has been recorded once in a period of 52 years, it is believed that it corresponds to a longer interval of occurrence. The record of hurricanes in Puerto Rico dates back to 1615. Tradition, history and the best personal knowledge, all give the "San Ciriaco" hurricane as that with the most intense rainfall and greatest flood flow.

A map of the Island showing the approximate distribution of maximum 24-hour rainfalls recorded since 1899 is included as Exhibit No. 2. It shows that a maximum 24-hour rainfall of 8 inches may be expected in any location in the Island. Regions of high intensities follow approximately the areas of heavy mean annual rainfall indicated by the Rainfall Map, Exhibit No. 1; that is, in general, higher concentrations may be expected to occur near the top and in the northern slopes of the Luquillo and Cordillera Central Mountain ranges than on the lower lands along the coastal regions.

Intensity-Duration-Frequency Relation of Storms

As stated above, the most complete information on rainfall is available at San Juan, where rainfall intensities during shorter durations, as well as daily rainfall, have been recorded for a long period. These records have been studied in great detail in order to obtain information on the pattern and behavior of rainfall at San Juan, which may be useful in determining the corresponding pattern and behavior in other sections of the Island where less complete data is available.

The recorded intensities of rainfall, in inches per hour, for 1, 2, 3, 6 and 24-hour durations in 101 storms at San Juan during the 1905-1950 period of record are given in Table No. 3 on page 364-19. These records have been

analyzed as to relation between intensity and frequency of occurrence and the result plotted on a logarithmic scale is shown on the accompanying Exhibit No. 3.

A regular pattern of rainfall is evidenced by the striking parallelism between the lines representing the intensity-frequency relation for these durations. It may be observed that in the lines representing the intensity-frequency relation for one to six-hour durations there is a distinct change in slope for intervals of occurrence greater than 10 years. This tendency is not evidenced in the line representing the 24-hour rainfall. As indicated in the graph, these lines may be represented by equations, as follows:

For intervals of occurrence less than 10 years:

1 hour rainfall	$i = 1.32\ T^{0.32}$	(1)
2 hour rainfall	$i = 0.90\ T^{0.32}$	(2)
3 hour rainfall	$i = 0.68\ T^{0.32}$	(3)
6 hour rainfall	$i = 0.40\ T^{0.32}$	(4)
24 hour rainfall	$i = 0.13\ T^{0.32}$	(5)

For intervals of occurrence above 10 years:

1 hour rainfall	$i = 1.82\ T^{0.18}$	(6)
2 hour rainfall	$i = 1.24\ T^{0.18}$	(7)
3 hour rainfall	$i = 0.94\ T^{0.18}$	(8)
6 hour rainfall	$i = 0.55\ T^{0.18}$	(9)
24 hour rainfall	$i = 0.13\ T^{0.32}$	(5)

Where i = intensity in inches per hour and
T = interval of occurrence at San Juan in years

The above set of equations represent the pattern of rainfall in San Juan. Their similarity suggests that all of them may be expressed in one or more general rainfall equation of the form

$$i = \frac{KT^x}{t^e}$$

in which in addition to the above definition of terms, t represents rainfall duration in hours. This general rainfall equation has been used in studies of rainfall in the United States, and the values of the coefficient K, and of the exponents e and x, have been presented by Bernard,[6] Yarnell,[7] and others[8] for the central and eastern part of the United States. If values of intensity (as ordinates) and durations (as abscissas) obtained from the above set of equations for intervals of occurrence of 5, 10, 20 and 50 years are plotted on a logarithmic scale, the points indicated in Exhibit No. 4 are obtained. Also plotted on this exhibit are points representing the highest intensities reported

6. See Appendix A, by Merrill Bernard, Chief, River and Flood Division, U. S. Weather Bureau, in "Low Dams" National Resources Committee, Washington, D. C.
7. "Rainfall Intensity - Frequency Data" by D. L. Yarnell, (U. S. Department of Agriculture Miscellaneous Publication No. 204, 1935.
8. "Storm Rainfall of Eastern United States" published by the Miami Conservancy District.

by the U. S. Weather Bureau at San Juan, during the 45 years of record (1905-1950), and which are as follows:

Duration	Inches Per Hour	Date
5 minutes	9.47	May 22, 1911
10 minutes	6.12	May 22, 1911
15 minutes	5.72	May 25, 1916
30 minutes	4.46	Nov. 11, 1931
1 hour	3.47	Nov. 11, 1931
2 hours	2.46	Aug. 15, 1944
3 hours	1.87	Aug. 15, 1944
6 hours	1.04	Nov. 11, 1931
24 hours	0.44	Dec. 13, 1910

It will be seen that the pattern of rainfall can be well represented by lines having a change in slope at a point corresponding to a duration of 1 hour 30 minutes, with a steeper slope for the longer durations. This pattern is similar to that which obtains in the United States, although the slopes of the lines and the point of change in slope have other values. For durations greater than 1 hour 30 minutes the lines indicating frequence of occurrence below 10 years are parallel. Above 10 years they are not exactly parallel but rather show a tendency to spread out at the right end. This is due to the difference observed in Exhibit No. 3 where the curves corresponding to six hour durations or less change to a smaller slope for intervals of occurrence greater than 10 years, while this tendency is not evidenced in the 24-hour rainfall. For durations smaller than 1 hour 30 minutes the information available from the rainfall records is very limited and there is no indication to the effect that the lines for the various intervals of occurrence should not be parallel.

Exhibit No. 4 gives a picture of the Intensity-Duration-Frequency relation of rainfall at San Juan, Puerto Rico, as complete as possible, within the limitations of the information available. As indicated on the graph, the intensity-duration-frequency relation for San Juan, P. R. may be expressed by four equations as follows:

For durations less than 1 hour 30 minutes:

Intervals of occurrence 10 years or less

$$i = \frac{1.32\ T^{0.32}}{t^{0.37}} \qquad (10)$$

Intervals of occurrence above 10 years

$$i = \frac{1.82\ T^{0.18}}{t^{0.37}} \qquad (11)$$

For durations greater than 1 hour 30 minutes:

Intervals of occurrence 10 years or less

$$i = \frac{1.56\ T^{0.32}}{t^{0.78}} \qquad (12)$$

Intervals of occurrence above 10 years

$$i = \frac{2.11\ T^{0.18}}{t^{0.74}} \qquad (13)$$

Where i = intensity in inches per hour
T = interval of occurrence in years
t = duration in hours

Maximum Storms in the Island

An analysis of the frequencies and intensities of the 24-hour rainfalls of large intensity which have occurred at two selected locations, where a larger number of storms have been recorded, Adjuntas and Jauca, and in the entire Island, is shown plotted logarithmically in Exhibit No. 5. This graph indicates consistency in the pattern of 24-hour rainfall in the different locations and for the entire Island. The points indicating frequencies of occurrence versus intensities fall approximately along parallel lines having the same slope as that of the intensity-frequency curves for San Juan shown in Exhibit No. 3. While the lines corresponding to San Juan, Jauca and Adjuntas have a single slope, that corresponding to the entire island indicates a tendency, previously observed in the short time rainfalls in San Juan, to change in slope for intervals of occurrence greater than 10 years. This similarity suggests a uniform pattern of rainfall in the island consisting of lines with slopes parallel to line (A) in Exhibit No. 5. It is possible that this pattern would be evidenced in all stations if sufficient records were available.

A thorough study of the short time records of a few stations with automatic recorders operated for short periods (1 to 7 years) within the last 14 years, (1938-1952) by the Soil Conservation Service gives the maximum intensities recorded during this period as follows:

Duration	Inches Per Hour	Date	Location
5 minutes	8.50	October 21, 1940	Las Mesas, Mayaguez
10 minutes	7.00	August 16, 1944	Las Mesas, Mayaguez
20 minutes	5.60	August 1, 1939	Las Mesas, Mayaguez
1 hour	3.30	August 5, 1939	Barrancón, Vieques
2 hours	2.55	August 5, 1939	Barrancón, Vieques

The stations above referred to are situated at such scattered locations as Mayaguex, Luquillo, Cayey, Adjuntas, Salinas (Aguirre), Arroyo, Río Piedras, Patillas, Comerío and Vieques. The above values, therefore, may be considered as a 5-year frequency record for the entire Island. They have been plotted, together with the 24-hour rainfall having a 5-year frequency, on Exhibit No. 6. It may be observed that two lines having a change in slope at the point corresponding to 1 hour 30 minutes, with a steeper slope for the longer durations and similar to those obtaining for San Juan in Exhibit No. 4, may be drawn through these points to represent the intensity-duration curve, of the maximum 5-year rainfalls in Puerto Rico. Furthermore, the slope of the line under 1 hour 30 minutes duration (0.37) is equal to that of the corresponding lines for different frequencies at San Juan (0.37).

The points for 24-hour rainfalls with frequencies of 10, 20, 30 and 50 years in the Island, taken-off from the curve on Exhibit No. 5, are also plotted on Exhibit No. 6. Lines thru these points and parallel to the 5-year frequency curve have been drawn to represent the estimated intensity-duration curves

for the maximum 10, 20, 30 and 50 year rainfalls in Puerto Rico. These lines follow a pattern similar to that indicated for San Juan in Exhibit No. 4 and have been indicated parallel throughout because of the consistent parallelism observed between the short duration curves in Exhibit No. 3 for San Juan and the 24-hour duration curve for the entire Island given in Exhibit No. 5.

A search of all available rainfall records during the last 50 years has indicated the following extraordinary storms during which the maximum intensities have been recorded in the Island:

Duration	Depth in Inches	Date	Location
48 hours	29.60	Sept. 13-14, 1928	Adjuntas
24 hours	23	August 8, 1899	Adjuntas
12 hours	18.22	Sept. 7, 1910	Naguabo
12 hours	17.40	March 3, 1933	Mayaguez
4 hours	10.10	May 19, 1940	Toro Negro Plant No. 2
45 minutes	4.30	November 18, 1941	Jauca

The highest 48-hour rainfall was recorded at Adjuntas during the "San Felipe" hurricane, on September 13-14, 1928. During these two days a total of 29.60 inches of rainfall was recorded at Adjuntas. During the same 48 hour period, 26.40 inches were recorded at Limani Station and 21.80 inches at Jauca Station, both of these in the vicinity of Adjuntas. Exhibit No. 9 shows the location of these stations and the approximate distribution of rainfall in the neighboring area during that storm.

The "San Ciriaco" storm, on August 8, 1899, has been discussed at the beginning of this chapter, and the approximate rainfall distribution during this storm is shown in Exhibit No. 8. The storm of March 3, 1933 in the area near Mayaguez caused an unusual flood of the Yagüez River which inundated part of the city of Mayaguez with heavy loss of property. According to the records in the Weather Bureau, rain started at 12:30 P.M., March 3 and stopped at 12:30 A.M., March 4.

The storm of May 19, 1940 covered most of the Island, with heavy concentration in the central section as indicated in Exhibit No. 10. It caused the greatest flood recorded at the Guayabal reservoir. The rainfall at Toro Negro Plant No. 1, near Villalba, was 11.73 inches during 24 hours with a concentration of 9.78 inches in four hours, while at Toro Negro Plant No. 2, on the northern side of the divide, it was 12.10 inches during 24 hours with a concentration of 10.10 inches in four hours, and at Guineo Dam it was 12.20 inches with a concentration of 10.05 inches in four hours.

The concentration of 4.30 inches in 45 minutes, which occurred during May 18, 1941, was reported at Jauca, one of the rainfall stations operated by the Water Resources Authority, located as shown in Exhibit No. 9.

These maximum recorded intensities have been plotted on Exhibit No. 6 in order to see how they fit into the estimated frequency curves for the maximum storms in the Island. It may be observed that the first four of these storms fall along the 50-year frequency curve while the last two fall about midway between the 20 and 30-year frequency curves. It is believed that this furnishes reasonable evidence that the estimated frequency-curves are not much out of line with what the actual expectancies may be. Exhibit No. 6 is offered as a tentative representation of the intensity-duration-frequency relation of maximum rainfalls in Puerto Rico, to be used until more complete information is available to determine its pattern with greater accuracy.

As indicated on the graph, the intensity-duration-frequency relation for maximum rainfalls in Puerto Rico may be expressed by four equations as follows:

For durations less than 1 hour 30 minutes:

Intervals of occurrence 10 years or less

$$i = \frac{2.11\ T^{0.32}}{t^{0.37}} \qquad (14)$$

Intervals of occurrence above 10 years

$$i = \frac{2.93\ T^{0.18}}{t^{0.37}} \qquad (15)$$

For durations greater than 1 hour 30 minutes:

Intervals of occurrence 10 years or less

$$i = \frac{2.33\ T^{0.32}}{t^{0.59}} \qquad (16)$$

Intervals of occurrence above 10 years

$$i = \frac{3.21\ T^{0.18}}{t^{0.59}} \qquad (17)$$

Exhibit No. 6 gives the interval of occurrence at which the intensities and durations indicated are expected to occur throughout the Island. It should be noted, however, that the interval of occurrence at which the same intensities and durations may be expected to recur at the same location in the Island will be comparatively longer.

As an item of interest it may be noted that rainfall in northern Florida, near Jacksonville, may be expressed by the following equations:

For durations less than 1 hour

$$i = \frac{2.17\ T^{0.18}}{t^{0.39}} \qquad (18)$$

For durations above 1 hour

$$i = \frac{2.22\ T^{0.18}}{t^{0.76}} \qquad (19)$$

These equations show some similarity between the pattern of rainfall in Florida and in San Juan, as may be expected from the fact that the maximum rainfall intensities in Puerto Rico often occur during tropical hurricanes, many of which go thru Florida. In particular, eq. (13) for durations above 1 hour 30 minutes at San Juan, P.R. and for intervals above 10 years is very similar to eq. (19) for durations above 1 hour at Jacksonville, Florida. Also equation (18) for durations less than 1 hour at Florida is very similar to equations (11) and (15) for durations less than 1 hour 30 minutes at San Juan and in the Island. Equations (16) and (17) for durations above 1 hour and

30 minutes in the Island give higher intensities than equation (19) for durations above 1 hour at Florida. This comparison is shown graphically in Exhibit No. 7.

TWO MAJOR FLOODS RECORDED IN PUERTO RICO

General

Records of past floods in Puerto Rico are very scanty. Since the year 1924 the Water Resources Authority, then Utilization of Water Resources, has had under operation a number of stream gaging stations throughout the Island. These stations, however, were intended to measure ordinary flows in relation with the development work of the Authority and have not been equipped to measure major floods. The absence of records may be partly due to the fact that most of the major floods have occurred during hurricanes when most of the people are too busy looking for protection of their own lives, and partly to lack of curiosity in determining afterwards the magnitudes of the floods.

Some records have been obtained of major floods occurred during the two following storms:

Date	Stream	Location
Sept. 13-14, 1928	La Plata River	Comerío Dam
May 19, 1940	Jacaguas River	Guayabal Dam

Comerío Dam Flood

Spillings over the Comerío Dam have been recorded since its construction in 1914 to the present time. The drainage area above this dam comprises 135 square miles. The highest flood during this thirty year period occurred during the San Felipe hurricane, on September 13-14, 1928. During this flood the elevation of the reservoir water surface was approximately as follows:

	Time	W. S. Elevation
Sept. 13	3 P.M. Wind increasing	475.0 (Spillway Crest)
	5 P.M. Began spilling	476.0
	6 P.M. All 3 sluice gates open	477.0
	9 P.M.	479.0
	10 P.M.	484.0
Sept. 14	12 Midnight	490.0
	1 A.M.	491.0
	2 A.M.	493.75
	3 A.M.	488.0
	4 A.M.	485.0
	5 A.M.	484.0
	6 A.M.	483.0
	7 A.M.	483.0
	8 A.M.	482.0
	9 A.M.	481.0
	10 A.M.	481.0
	11 A.M.	480.0
	12 Noon	479.0

The sluice gates opened consist of:

1 - 5' x 5' sluice gate with center line at elev. 434.0
1 - 5' x 5' sluice gate with center line at elev. 408.5
1 - 5' x 5' sluice gate with center line at elev. 389.0
1 - 5' x 5' sluice gate with center line at elev. 382.0

The Comerío Dam is of the Ambursen flat slab type, with an overflow spillway section 360 feet long and two abutment sections 80 feet and 54 feet long. The spillway crest is at elevation 475 and the top of the abutmer sections, at elevation 490. The spillway is not obstructed by bridge piers so that its total length is available for spilling. At its maximum elevation, the water overtopped the abutment sections by 3.75 feet.

Exhibit No. 11 gives a graph of the estimated discharge over the spillway and thru the sluices during this flood. The peak discharge at 3 A.M., September 14, reached 116,000 cfs. Exhibit No. 11 shows a curve indicating the relation between the discharge over the spillway and thru the sluice gates, and the stored volume above the spillway crest of the Comerío Dam. Routing this flood over the reservoir gives the inflow curve shown, which indicates a peak inflow of 120,000 cfs., equivalent to a discharge of 890 cfs. per square mile of drainage area. The drainage basin above Comerío Dam is indicated in Exhibit No. 9 with isohyetals indicating the total rainfall during this hurricane.

Guayabal Dam Flood

The highest flood recorded at Guayabal Dam since its construction in 1914 occurred during the storm of May 19, 1940. The drainage area above Guayabal Dam comprises 43.4 square miles. It is located on the South central section of the Island, to the southeast of the drainage area above the Caonillas damsite. Its location and the approximate distribution of rainfall during this storm is indicated in Exhibit No. 10.

The recorded elevation of the reservoir water surface during this flood were as follows:

	Time	W. S. Elevation
May 19	6:00 A.M.	325.00 Elevation Concrete Crest
	6:00 P.M.	326.45 Top of Flashboards on Crest
	6:50 P.M.	329.00 Flashboards Washed Away
	7:25 P.M.	333.00
	8:15 P.M.	334.15 Overflowed the Abutment Section
	9:30 P.M.	333.00
May 20	6:00 A.M.	325.50

The Guayabal Dam is an Ambursen flat-slab dam, with an overflow spillway section having a total length of 756 feet (714 feet net length) and an abutment section 918 feet long. The top of the flat slab on the abutment section is at elevation 333. There is an opening 1 foot high and of 816 feet net length between the top of the slab and the underside of the highway bridge slab over the dam. At the peak of the flood water overflowed thru this opening and the maximum water surface reached a level 1.15 feet above the top of the flat slab.

Exhibit No. 12 indicates the estimated spillway discharge during this flood. The peak discharge at 8:15 P.M. reached about 70,000 cfs. Exhibit

No. 12 gives the relation between spillway discharge and volume stored above the spillway crest of Guayabal Dam. Routing of this flood over the Guayabal reservoir gives the inflow curve shown in Exhibit No. 13. The maximum peak inflow occurred at 7:50 P.M. and amounted to 78,000 cfs., equivalent to a discharge of 1,820 cfs. per square mile of drainage area.

Discussion of Major Floods

The flood flows in cubic feet per second per square mile during the two major floods discussed above have been plotted in Exhibit No. 14 against the drainage areas in square miles. For comparison, fifteen record breaking floods in the United States and foreign rivers, listed in table No. 4, have been plotted in this exhibit. These floods have been taken from a compilation of 997 unusual flood peaks in the United States and other countries, made by C. S. Jarvis, and W. P. Creager, given on figure 1, page 126 of the book "Engineering for Dams - Vol. I," published by John Wiley & Sons, Inc. Curve A is an enveloping curve given by the authors of this book and follows the general trend of the maximum floods compiled with the exclusion of some exceptional floods, as indicated in Exhibit No. 14. It may be noticed that the Guayabal and Comerío floods fall substantially along the values given by this enveloping curve. This comparison points out the unusual magnitudes of the Guayabal and Comerío floods with relation to their drainage areas and indicates the suitability of curve A as a basis for estimating maximum floods from similar areas in Puerto Rico.

Although a discussion of the relation between maximum flood flow and spillway capacity of a dam, or outflow capacity of a culvert, are outside of the scope of the paper - in closing, the author would like to caution against the application of the rainfall data given herein for determining the maximum flow from small drainage areas, without considering also the ratio between the volume of water produced by the rainfall causing the maximum peak flow, and the amount of pondage available back of the outflow device for storing part of this volume of water. In other words, although the peak flow computed by using the highest intensity of rainfall that will probably occur of a duration equal to the "time of concentration" of the area may have a very high value in cfs, quite often when working with small drainage areas the total volume of water from the critical rainfall is small compared to the available pondage back of the outflow device, and the required outflow capacity of the later may only be a fraction of the peak flood flow so computed.

TABLE NO. 1

RECORDED 24-HOUR RAINFALLS ABOVE 6 INCHES IN PUERTO RICO

Date	Location	Inches
1899		
Aug. 8	Adjuntas	23.00
	Cayey	11.62
	Mayaguez	8.40
	Isabela	11.20
	Lajas	11.20
	Canóvanas	7.15
	Bayamón	6.12
	Isolina	18.00
1900		
Apr. 23	Luquillo	12.23
Apr. 28	Vieques	8.00
Apr. 29	Fajardo	8.45
	Humacao	6.60
	San Lorenzo	8.31
	Caguas	7.00
	Canóvanas	6.25
June 4	Caguas	8.05
June 7	San Germán	6.85
June 8	Lajas	6.00
June 10	Yauco	7.95
July 31	San Lorenzo	7.25
Aug. 8	Adjuntas	11.54
1901		
Jan. 23	Coamo	8.10
May 26	Maunabo	7.30
Mar. 17	Manatí	9.32
	Morovis	8.30
July 6	Luquillo	17.02
July 8	Fajardo	7.62
Sept 12	Utuado	8.50
	Fajardo	6.48
	Cayey	6.47
	Adjuntas	10.00
	Mayaguez	6.24
	Barros	6.10
	Santa Isabel	6.35
Oct. 9	La Isolina	6.60
Nov. 17	Arecibo	8.00
Nov. 18	Manati	9.00
	Las Marías	6.40
	Cayey	7.65
	Barros	6.80
1902		
May	Humacao	6.01
June 7	Guayama	6.40
June 16	Cayey	6.83
1903		
Dec.	Canóvanas	6.40
1904		
None		
1905		
Sept 22	Humacao	6.15
Oct. 4	La Carmelita	6.40
1906		
None		
1907		
May 28	Yauco	7.10
	Guánica Central	6.20
1908		
None		
1909		
May 13	Humacao	7.83
Aug. 1	Guánica	6.23
Aug. 22	Cidra	6.25
	Cayey	6.09
Nov. 12	Maricao	6.50
	Guayama	10.60
	La Carmelita	6.00
	San Salvador	6.43
Nov. 13	Aibonito	7.45
	Maunabo	9.49
	Naguabo	8.28
	Blanco Res.	6.99
	Central Aguirre	8.99
	Aibonito	7.45
	Yabucoa	12.90
	Humacao	10.42
1910		
July 18	Jayuya	6.44
Aug. 7	Río Piedras	6.10
Sept. 6	Canóvanas	7.75
Sept. 7	Caguas	6.00
	Río Blanco	13.54
	Naguabo	18.22
	Maunabo	10.50

TABLE NO. 1 (Cont.)

Date	Location	Inches
1910		
Sept. 7	Humacao	14.90
	Fajardo	6.50
	Rio Piedras	6.50
	Cidra	8.30
	Central Ingenio	10.07
	Comerío Falls	10.00
	Corozal	12.10
	Vieques	6.36
Dec. 14	San Juan	10.55
Dec. 15	Comerío Falls	6.80
1911		
May 24	San Germán	8.00
Oct. 28	Yabucoa	10.30
1912		
Sept. 9	Guayama	6.20
Oct. 7	Cayey	7.00
Oct. 8	Carite Dam	7.47
	Juncos	6.25
	Hda. Potala	7.35
	Toro Negro Dam	8.00
	Central Aguirre	7.44
	Guayama	7.34
	Juana Díaz	10.72
	Patillas Dam	8.00
	Ponce	7.60
	Hda. Oriente	7.46
Oct. 31	Añasco	6.17
	Mayaguez	7.84
1913		
Sept.12	Hda. Destino	6.50
Oct. 4	Dorado	6.50
1914		
May 3	Cidra	6.12
	Juncos	9.10
	Humacao	9.84
	Oriente	8.40
	Naguabo	10.70
1915		
Apr. 6	Arecibo	6.50
Apr. 7	Arecibo	6.25
	Barceloneta	6.31
	San Juan	6.19

Date	Location	Inches
1915		
Apr. 8	Canóvanas	6.05
	Dorado	6.38
	Manatí	9.41
	Barceloneta	7.12
Nov. 27	Arecibo	6.50
	Barceloneta	11.36
	Manatí	6.84
Nov. 28	Barceloneta	10.09
Dec. 7	Barceloneta	7.56
1916		
July 14	Cayey	7.05
	Toro Negro	6.10
Aug. 22	Aibonito	8.10
	Jayuya	7.10
	Carite Camp	6.97
	Cayey	9.00
	Toro Negro	6.00
1917		
Apr. 24	Toro Negro	7.56
Nov. 20	Barceloneta	6.00
	Manatí	6.40
1918		
July 28	Cepero	6.01
Sept 10	Yabucoa	6.00
Sept 11	Humacao	8.19
	Patillas Dam	6.29
Nov. 5	Toro Negro Dam	6.10
1919		
June 11-12	Canóvanas	14.83
June 12	Cangrejo	7.39
	Fajardo	6.60
	Yabucoa	6.75
	Isidora	6.00
1920		
None		
1921		
Sept 10	Cabo Rojo	14.05
	San Germán	8.50
Sept 11	Mayaguez	9.50

TABLE NO. 1 (Cont.)

Date	Location	Inches
1922		
None		
1923		
None		
1924		
Aug. 18	Fajardo	6.35
Aug. 19	Aibonito	6.94
Nov. 10	Humacao	6.23
	Juncos	7.20
1925		
Sept 26	Naguabo	6.09
1926		
Jan. 15	Dorado	7.05
July 23	Santa Isabel	6.00
	Naguabo	8.57
	Peñuelas	9.00
	San Cristóbal	7.50
	Santa Rita	8.80
	Barros	9.62
July 24	Dorado	6.00
	Isabela	10.00
	Canóvanas	9.68
	Caguas	7.20
	Cidra	9.37
	Comerío Falls	6.49
	Guayabal Dam	7.00
	Lares	9.80
	Maricao	13.00
	Rio Grande	12.36
	Utuado	7.20
Sept 15	Isabela	6.00
Sept 16	Lares	6.75
	Utuado	7.50
1927		
Mar. 4	Toa Baja	10.35
May 22	Barceloneta	7.65
Oct. 30	Fajardo	9.13
	Humacao	6.32
	Yabucoa	6.20
	Canóvanas	10.10
	La Fe	12.50

Date	Location	Inches
1927		
Oct. 30	Maunabo	6.09
	Paraíso	7.40
	Caguas	9.36
	Juncos	7.00
Oct. 31	Humacao	6.80
	Rio Grande	10.20
	San Lorenzo	6.82
	San Lorenzo	8.10
Nov. 1	Maricao	7.00
1928		
May 6	Cidra	8.13
	Barceloneta	7.20
	La Fe	12.20
May 7	Cabo Rojo	7.10
	Coloso	8.60
	Dorado	6.25
	Humacao	8.53
	Mayaguez	8.50
	San Germán	9.90
	Santa Rita	6.60
	Adjuntas	8.50
	Barros	6.23
	Caguas	7.76
	Jayuya	9.03
	Limani	7.90
	Jauca	8.15
	Arenas	6.38
Aug. 3	Potala	6.45
	Barros	7.06
	Cayey	7.70
	Cidra	6.82
Aug. 4	Santa Isabel	6.60
Aug. 5	Coamo	8.60
Sept 13	Isabela	6.36
	Mayaguez	7.00
	San Juan	7.39
	Yabucoa	10.00
	Adjuntas	18.00
	Barros	10.22
	Carite Camp	6.07
	Cidra	10.00
	La Isolina	7.14
	Maricao	10.00
	Rio Grande	12.50
	Patillas Dam	6.00
	Rio Piedras	10.25
	Limani	11.00
	Jauca	13.80

TABLE NO. 1 (Cont.)

Date	Location	Inches
1928		
Sept 14	Coloso	7.82
	Fajardo	12.28
	Guayama	8.85
	Humacao	6.40
	Adjuntas	11.60
	Carite Camp	6.03
	Rio Grande	12.00
	San Lorenzo	6.05
	Vieques	10.00
	Paraíso	12.00
	San Cristóbal	12.00
	Comerío Falls	15.00
	Guayabal Res.	6.20
	Juncos	6.00
	Lares	14.00
	Bayamón	9.41
	La Fe	12.00
	Dorado	12.00
	Río Yerbas	8.25
	Limaní	15.40
	Jauca	8.00
	Río Blanco	6.90
Sept 15	Coloso	6.35
1929		
May 28	Fajardo	6.30
1930		
June 12	Fajardo	7.30
1931		
June 28	San Lorenzo	9.90
	San Lorenzo	9.20
Sept. 2	Jauca	7.95
	Yahuecas	6.60
	San Cristóbal	6.56
Sept. 3	Guineo Dam	7.00
	Guayabal	6.30
	Maricao	6.80
	Peñuelas	10.84
	Río Yerbas	8.75
	Adjuntas	7.36
	Limaní	7.25
Nov. 11	Barcelonota	7.30
	Quebradillas	8.17
	San Juan	7.92
Nov. 29	Vieques	11.00
	Vieques Sugar Co.	10.00

Date	Location	Inches
1932		
May 6	Colón	6.25
	Maricao	6.50
May 7	Isabela	6.32
	Peñuelas	7.89
	Guineo Res.	7.20
	Toro Negro Res.	7.40
Sept. 1	Maunabo	6.55
Sept 26	Barros	9.04
	Bayaney	7.50
Sept 27	Coloso	8.45
	Isabela	7.45
	Mayaguez	6.10
	Río Piedras	6.15
	Sabana Grande	7.25
	Cayey	7.25
	Comerío Falls	8.60
	Fronton	6.31
	Lares	7.30
	Maricao	16.00
	Matrullas	7.08
	San Lorenzo	11.00
	San Sebastián	8.30
	Toro Negro Res.	4.90
	Adjuntas	11.70
	Blanco & Guaba	7.77
	Jauca	7.75
	Yahuecas	6.70
Sept 28	Yerbas	6.10
1933		
Mar. 3	Cabo Rojo	11.15
	Mayaguez	17.40
May 1	Vieques	7.00
	Maunabo	6.40
	La Fe	8.25
	San Cristóbal	7.68
May 2	Vieques Island	6.18
	Yabucoa	8.50
May 31	San Cristóbal	8.65
1934		
None		
1935		
Feb. 3	Fajardo	6.65
Nov. 15	La Mina	8.58
Dec. 7	La Mina	9.30

TABLE NO. 1 (Cont.)

Date	Location	Inches
1936		
May 20	Yabucoa	6.50
	Paraíso	6.05
May 21	Humacao	8.10
	San Lorenzo	8.80
	Yabucoa	6.93
June 16	Ensenada	6.85
June 17	Santa Rita	6.80
Sept 28	La Mina	6.50
	Río Blanco	6.60
Dec. 28	La Mina	10.65
Dec. 29	La Mina	9.05
	Río Blanco	6.68
Dec. 30	Yabucoa	7.45
	Maunabo	6.36
1937		
Jan. 11	Bayamón	6.34
Apr. 29	Guineo Res.	4.18
Aug. 25	Río Blanco	6.00
Nov. 30	Guayama	6.05
1938		
Feb. 5	Quebradillas	7.10
Feb. 6	Camuy	6.11
Mar. 29	La Mina	6.01
May 16	Lares	6.00
June 13	San Juan	6.18
	La Fe	8.20
	Paraiso	10.80
	San Cristóbal	8.87
	Vieques	6.78
	Vieques	7.68
	Fajardo	10.30
	La Mina	10.87
June 14	Yunes	5.42
	Mameyes	6.10
	Dos Bocas	6.06
	Isabela	6.22
Nov. 6	Josefa	8.15
Nov. 6	Garzas Res.	7.00
	La Fe	8.07
Nov. 7	La Mina	6.36
	Río Blanco	7.45
	Río Blanco (near)	7.20
Nov. 8	Aguirre	7.80
1939		
Nov. 29	La Mina	6.26

Date	Location	Inches
1940		
Jan. 28	Barceloneta	8.00
Feb. 2	La Mina	9.00
May 18	Peñuelas	6.08
	Vieques	10.00
May 19	Fajardo	6.50
	Paraíso	9.25
	Adjuntas	6.00
	Jayuya	8.64
	Crocovis	8.18
	Toro Negro Res.	12.10
	Villalba - Toro Negro HEP #2	11.73
	La Fe	10.15
	La Mina	8.37
	Jauca	9.10
May 20	Guineo Res.	7.80
1941		
May 6	La Mina	12.34
	Paraíso	6.00
May 7	Río Blanco	6.14
May 21	Canóvanas	9.50
May 31	Fajardo	6.95
Sept 27	Santa Isabel	6.06
	San Francisco	7.90
Sept 30	Caguas	6.28
Dec. 14	La Mina	8.19
1942		
May 3	Barceloneta	6.90
1943		
Apr. 27	Guayama	6.98
Apr. 28	Patillas	9.26
May 16	Paraíso	6.43
	Río Blanco	7.44
	Río Blanco	7.13
June 16	Aibonito	9.20
	Barranquitas	10.60
	Carite	6.80
	Cubuy	9.15
Oct. 14	Yauco	6.30
	San Germán	6.40
	Adjuntas	9.92
	Aibonito	8.30
	Cidra	9.20
	Guineo Res.	8.10
	Maricao	9.70

TABLE NO. 1 (Cont.)

Date	Location	Inches
1943		
Oct. 14	Limani	6.05
	Crocovis	6.03
	Toro Negro Res.	7.70
	San Francisco	6.75
Oct. 15	Carite Camp	8.02
	Jájome Alto	9.75
	Guineo Res.	7.33
	Jayuya	8.06
	Toro Negro Res.	9.90
	Canóvanas	6.08
	Carzas	9.45
	Cayey	14.10
1944		
June 14	Paraíso	6.37
July 12	Naguabo	6.60
	Yabucoa	6.80
	Toro Negro	7.95
Aug. 14	Paraíso	6.83
	Gurabo	7.54
	Guineo	9.35
	Villalba	7.29
Sept 11	Jájome Alto	6.28
Oct. 30	Comerío Falls	6.86
1945		
May 26	Guineo	7.13
	Toro Negro	7.45
Aug. 3	Cayey	6.15
Aug. 4	Ponce	6.11
	Santa Rita	6.35
	Cayey	6.00
	Guineo	8.54
	Jájome Alto	6.20
	Maricao	8.00
	Matrullas Dam	6.55
	San Lorenzo	7.35
	Toro Negro	7.90
	Villalba	6.38
1946		
Nov. 16	Humacao	6.30
1947		
May 31	San Lorenzo	7.54

Date	Location	Inches
1948		
Sept. 2	Juncos	6.09
Sept. 3	Caguas	6.89
	Río Blanco	10.30
Sept 16	Garzas	6.20
	Santa Rita	8.30
	San Germán	6.22
	Sabana Grande	8.48
	San Francisco	13.80
1949		
Sept 21	San Francisco	8.10
	Ensenada	6.35
	Sta. Isabel	6.00
	Yauco	8.45
	Santa Rita	8.30
	Jayuya	6.00
	Peñuelas	6.25
	San Lorenzo	7.26
Sept 22	Coamo Dam	7.55
	Juana Díaz Camp	6.71
	Ponce	6.37
	Río Cañas	6.36
	Sábana Grande	6.02
	Adjuntas	6.09
	Carite Camp	6.60
	Guineo Res.	7.23
	Peñuelas	6.94
	San Lorenzo	6.30
	Toro Negro Res.	6.38
Sept 23	St. Just	6.00
1950		
Nov. 29	Lajas	6.35
Nov. 30	San Francisco	15.22
	Ensenada	9.03
	Guayama	7.38
	Sabater	6.15
	Yauco	8.20
	Coamo	7.19
	Juana Díaz Camp	7.29
	Río Cañas	9.04
	Río Jueyes	8.04
	San Germán	6.20
	Santa Rita	8.50
	Villalba	7.80
	Carite Camp	9.00
	Carite Plant #1	8.55
	Guayabal Res.	6.20
	Jájome Alto	6.65
	Peñuelas	6.09

TABLE NO. 2

MAXIMUM 24-HOUR RAINFALL INTENSITIES RECORDED
IN PUERTO RICO DURING THE DIFFERENT MONTHS
Period 1899-1950

Month	Date	Year	Place	Inches Rainfall
January	23	1901	Coamo	8.10
February	5	1938	Quebradillas	7.10
March	3	1933	Mayaguez	17.40
April	23	1900	Luquillo	12.33
May	6	1928	La Fe	12.20
June	11-12	1919	Canóvanas	14.83
July	6	1901	Luquillo	17.02
August	8	1899	Adjuntas	23.00
September	7	1910	Naguabo	18.22
October	15	1943	Carite Camp	14.10
November	13	1909	Yabucoa	12.90
December	13-14	1910	San Juan	10.55

TABLE NO. 3

MAXIMUM RAINFALLS IN SAN JUAN, P. R.

Date	Rainfall, Inches				
	1 hour	2 hour	3 hour	6 hour	24 hour
July 12, 1905	1.80	2.36	2.70	2.90	3.01
April 3, 1906	1.06	2.21	2.97	4.44	4.55
Sept. 22,1906	1.20	1.20	1.61	1.69	1.71
May 20, 1907	1.36	1.47	1.48	1.58	1.69
Jan. 24, 1909	1.13	1.37	2.28	2.67	2.73
Nov. 23, 1909	1.09	1.34	1.68	1.92	1.93
April 9, 1910	1.23	2.04	2.14	2.17	2.17
June 22, 1910	1.64	1.75	1.98	3.43	3.60
Sept. 6, 1910	2.50	4.21	4.27	4.79	5.42
Dec. 14, 1910	2.24	3.29	3.80	6.14	10.55
April 18,1911	1.01	1.25	1.40	1.44	1.44
May 22, 1911	1.46	1.62	1.62	1.62	1.96
July 22, 1911	1.04	1.31	1.31	1.32	1.39
Sept. 17,1911	1.47	1.68	1.68	1.68	1.68
Dec. 9, 1911	1.34	1.49	1.61	2.10	2.12
May 15, 1912	1.49	1.59	1.61	1.62	1.63
Sept. 15,1912	1.43	1.48	1.51	1.53	1.68
May 4, 1913	1.22	1.76	1.96	2.30	2.66
Sept.21, 1913	1.03	1.07	1.08	1.08	1.48
May 3, 1914	1.15	1.78	1.84	2.18	2.18
Oct. 5, 1914	1.17	1.33	1.36	1.71	1.71
Nov. 5, 1914	2.49	2.71	2.72	2.74	2.74
April 7, 1915	1.84	2.52	3.01	4.18	6.19
July 20, 1915	1.22	1.49	1.58	2.39	2.41
Dec. 6, 1915	1.25	2.38	2.40	2.46	2.52
Sept. 5, 1916	1.14	1.20	1.31	1.32	2.10
Sept. 16,1916	1.25	1.33	1.33	1.33	1.33
May 10, 1917	1.21	2.52	2.62	2.70	2.70
Feb. 23, 1918	2.00	2.27	3.60	4.36	4.36
Oct. 24, 1918	2.24	3.30	3.31	3.34	3.34
June 11, 1919	1.98	2.98	3.98	4.28	5.22
Nov. 24, 1919	1.06	1.26	1.27	1.27	1.27
Jan. 1, 1920	1.00	1.69	2.04	2.06	2.06
Sept. 17,1920	1.09	1.30	1.46	1.48	1.48
Sept. 28,1920	1.09	1.42	1.56	1.65	1.65
Oct. 23, 1920	1.81	2.05	2.05	2.05	2.05
May 1, 1921	1.07	1.08	1.08	1.08	1.27
Dec. 1, 1922	1.95	2.62	2.73	2.84	4.64
Sept. 3, 1923	1.19	2.16	2.39	2.44	2.58
Oct. 15, 1923	1.36	1.38	1.39	1.43	1.57
Nov. 14, 1923	1.14	1.24	1.28	1.31	1.31
Nov. 15, 1923	2.14	2.51	2.52	2.52	2.54
April 26,1924	2.04	2.55	2.55	2.55	2.65
July 21, 1924	1.14	1.17	1.18	1.18	1.18
Sept. 23,1924	1.86	1.97	2.01	2.01	2.01
Oct. 31, 1924	1.40	1.90	1.91	1.91	1.91
Jan. 14, 1926	1.33	1.33	1.52	2.66	2.67
July 23, 1926	1.10	1.80	2.16	2.76	3.66
Aug. 16, 1926	1.68	1.94	2.11	2.13	2.70
March 5, 1927	1.16	1.72	2.26	2.55	2.55

TABLE NO. 3 (Cont.)

April 14,1927	1.31	2.56	2.91	3.21	3.50
June 23, 1927	1.05	1.12	1.41	1.71	2.22
May 7, 1928	2.01	2.63	2.79	3.41	4.07
July 10, 1928	1.33	1.72	1.91	1.95	2.55
Aug. 3, 1928	3.17	3.37	3.50	3.51	5.51
Sept. 13,1928	1.00	2.00	2.80	3.39	7.39
June 30, 1929	1.06	1.15	1.24	1.27	1.27
Sept. 1, 1929	1.07	1.29	1.45	1.73	2.18
Jan. 9, 1930	1.25	1.86	1.91	1.92	1.94
Nov. 19, 1930	1.04	1.56	1.70	1.71	1.78
Dec. 6, 1930	1.05	1.06	1.10	1.11	1.12
March 21,1931	1.44	1.79	1.88	1.91	1.91
June 20, 1931	1.02	1.24	1.27	1.44	1.68
July 29, 1931	1.92	2.61	2.89	2.92	2.92
Nov. 11, 1931	3.47	4.36	5.16	6.24	7.92
April 29,1932	1.08	1.88	1.91	1.94	1.94
June 27, 1932	1.18	1.27	1.32	1.38	1.76
Oct. 12, 1932	1.10	1.16	1.26	1.32	1.37
June 20, 1933	1.13	1.30	1.30	1.30	1.30
Jan. 3, 1934	2.91	4.11	4.32	4.52	4.52
June 23, 1934	1.15	1.63	1.82	1.86	1.86
Sept.25, 1934	1.45	2.18	3.36	3.73	3.94
Nov. 9, 1934	1.45	1.54	1.86	1.91	2.33
Feb. 7, 1935	1.10	1.66	1.74	1.90	1.90
May 25, 1936	2.10	2.27	2.28	4.49	4.97
Aug. 10, 1936	1.29	1.31	1.34	1.39	1.46
Nov. 2, 1936	1.05	1.33	1.34	1.57	1.57
March 28,1938	1.48	1.59	1.71	2.25	2.25
Sept. 9, 1938	1.11	1.45	1.45	1.45	1.45
May 6, 1941	1.00	1.81	1.95	2.15	2.82
Nov. 21, 1941	1.04	1.07	1.10	1.17	1.17
Sept. 1, 1942	1.06	1.15	1.20	1.23	1.28
Nov. 28, 1942	1.41	1.52	1.52	1.83	1.83
Aug. 15, 1944	3.11	4.93	5.61	5.91	9.83
Sept. 18,1944	1.82	2.03	2.03	2.07	2.09
June 14, 1946	1.85	1.93	2.01	2.02	2.15
May 30, 1947	1.04	1.12	1.13	1.13	1.26
June 2, 1947	1.38	1.61	1.90	1.90	2.16
Aug. 10, 1947	2.02	2.33	2.36	2.37	2.37
Aug. 28, 1947	1.63	1.71	1.72	1.73	1.76
Sept. 22,1947	1.09	1.11	1.11	1.23	1.81
May 26, 1948	1.40	1.43	1.43	1.43	1.49
June 7, 1948	1.49	1.62	1.67	1.67	2.09
July 3, 1948	1.09	1.09	1.09	1.09	1.10
Dec. 2, 1949	1.21	1.83	1.84	1.93	1.76
July 18, 1950	1.10	1.85	1.93	2.37	3.59
Aug. 15, 1950	1.18	1.20	1.20	1.20	1.20
June 9, 1951	1.10	1.30	1.31	1.35	1.36
July 14, 1951	1.30	2.16	2.17	2.30	2.46
Aug. 15, 1951	1.20	1.22	1.22	1.63	1.73
Dec. 3, 1951	1.48	1.57	1.57	1.76	3.43

TABLE NO. 4

UNUSUAL FLOOD PEAKS, U. S. AND FOREIGN RIVERS*

Item No.	Stream and Location	Drainage Area Sq. Mi.	Flood Peak C.F.S.	C.F.S. Per Sq. Mi.	DATE
92	Pine Tree Canyon, California	35	59,500	1,700	August 12, 1931
99	Cameron Cr., California	3.59	13,500	3,760	Sept. 30, 1932
605	Sergeant Major Cr., Oklahoma	37	53,650	1,450	April, 1934
816	Seco Cr., Texas	153	230,000	1,500	May 31, 1935
818	Salado Cr., Texas	148	143,000	966	Sept. 10, 1921
822	Johnson Cr., Texas	111	138,000	1,240	July 2, 1932
834	Guadalupe R., Texas	65.3	84,300	1,290	July 1, 1932
836	James R., Texas	60.8	105,000	1,730	July 1, 1932
852	Alazan Cr., Texas	17.1	33,400	1,950	Sept. 1921
855	Bunton Branch, Texas	4.1	13,800	3,370	June 30, 1936
977	Elkhorn Cr., W. Virginia	44	60,000	1,360	June, 1901
986	Orba R., Orbicella, Italy	58	80,000	1,380	August, 1935
989	Wailua, Hawaii	23	45,000	1,950	January, 1921
991	Orba R., Martina, Italy	18.3	34,200	1,870	August, 1935
992	Orbicella R., Italy	10	20,100	2,010	August, 1935

* Highest flood peaks for drainage areas up to 150 square miles abstracted from Table No. 1, pp. 101-103 of "Engineering for Dams".

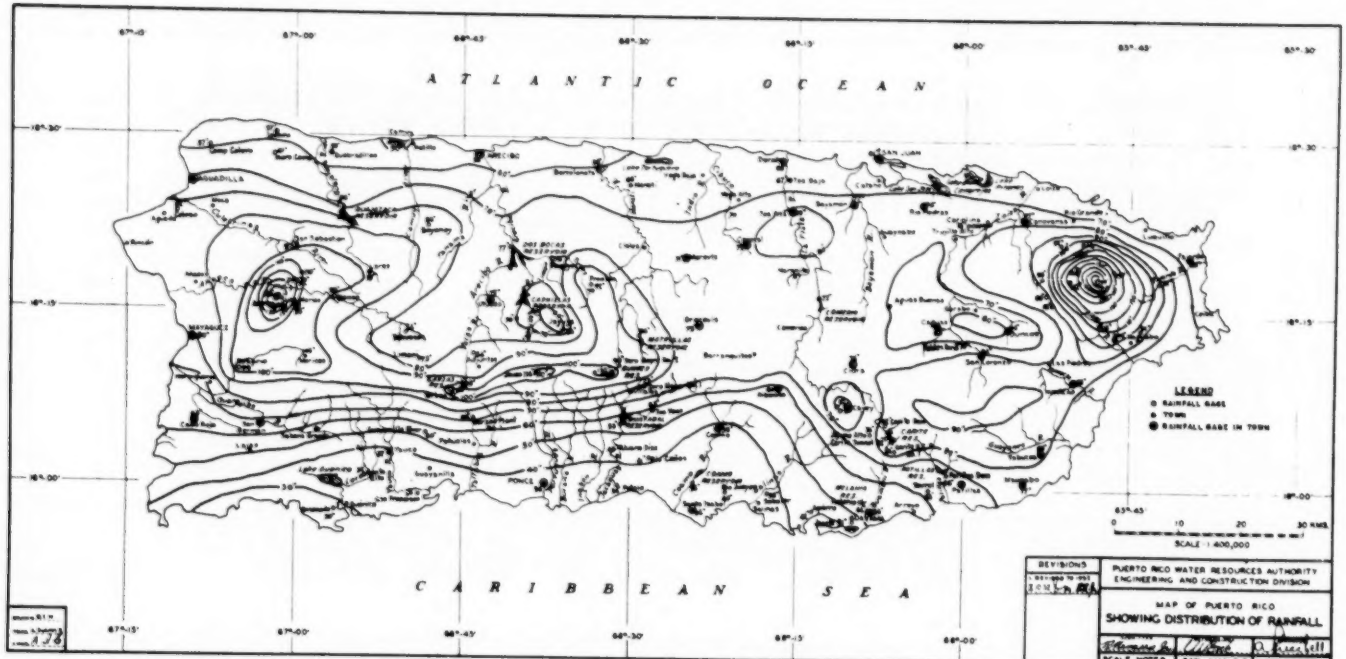
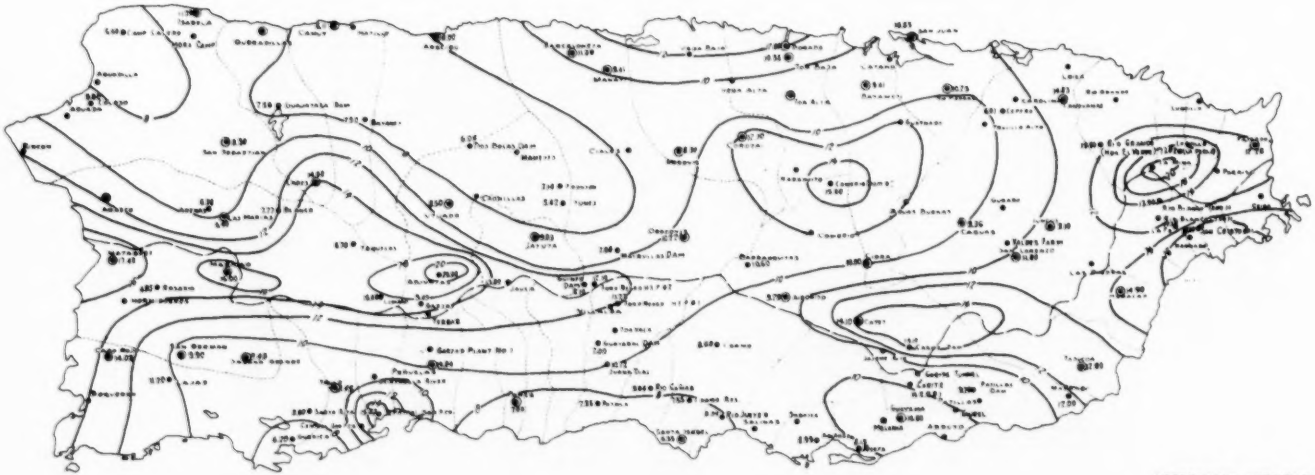

ATLANTIC OCEAN
CARIBBEAN SEA
LEGEND
RAINFALL GAGE
70MM
RAINFALL GAGE IN 70MM
SCALE 1:400,000
PUERTO RICO WATER RESOURCES AUTHORITY
ENGINEERING AND CONSTRUCTION DIVISION
MAP OF PUERTO RICO
SHOWING DISTRIBUTION OF RAINFALL
SCALE NOTED
SAN JUAN, P.R.
JULY, 1952

EXHIBIT NO. 1


APPROXIMATE DISTRIBUTION OF
MAXIMUM 24-HOUR RAINFALL
IN PUERTO RICO
SEPTEMBER, 1943
Exhibit No. 2

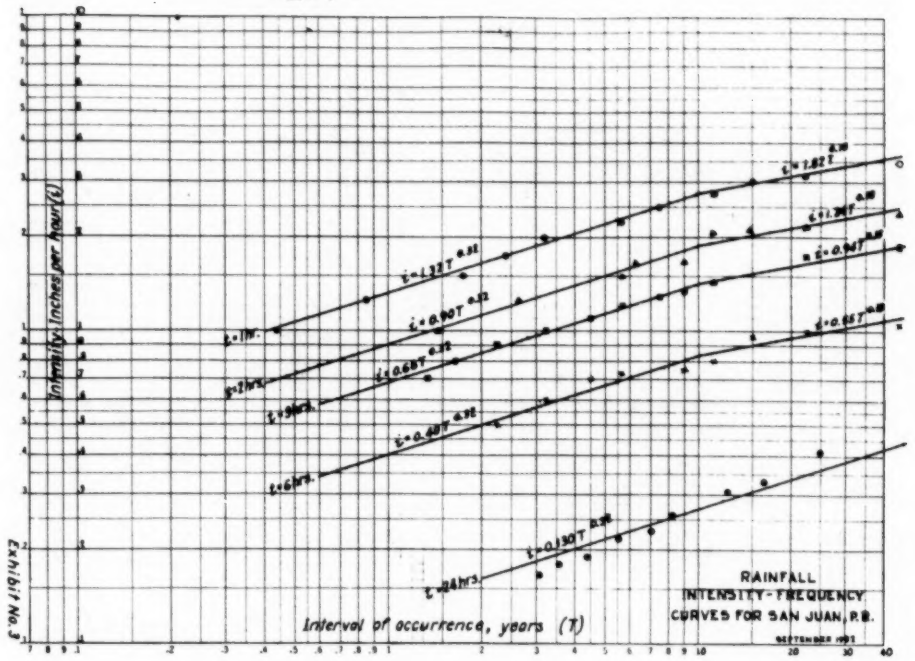

Intensity (i) in inches per hour
Interval of occurrence, years (T)
i = 1.32 T^0.31
i = 0.90 T^0.32
i = 0.68 T^0.32
i = 0.49 T^0.32
i = 0.30 T^0.28
i = 7.82 T^0.30
i = 1.96 T^0.28
i = 0.94 T^0.28
i = 0.65 T^0.28
t = 1hr.
t = 2hrs.
t = 3hrs.
t = 6hrs.
t = 24hrs.
RAINFALL
INTENSITY - FREQUENCY
CURVES FOR SAN JUAN, P.R.
SEPTEMBER 1951

Exhibit No. 3

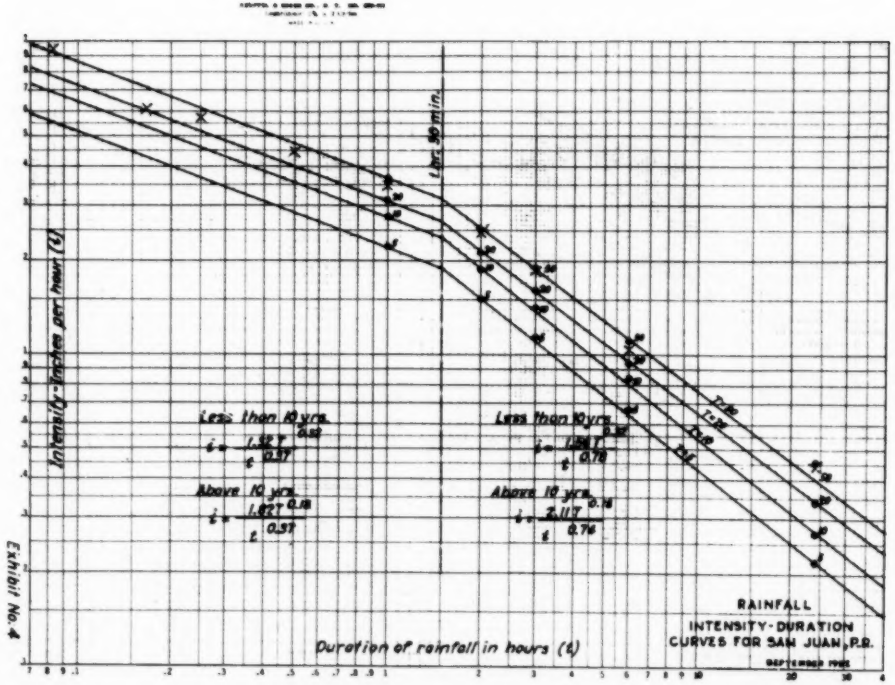

Intensity-Inches per hour (i)
Less than 10 yrs.
i = 1.52 T^0.02 / t^0.37
Above 10 yrs.
i = 1.82 T^0.18 / t^0.97
Less than 10 yrs.
i = 1.58 T^0.22 / t^0.78
Above 10 yrs.
i = 2.11 T^0.14 / t^0.76
T=50
T=25
T=10
T=5
Duration of rainfall in hours (t)
RAINFALL
INTENSITY-DURATION
CURVES FOR SAN JUAN, P.R.

Exhibit No. 4

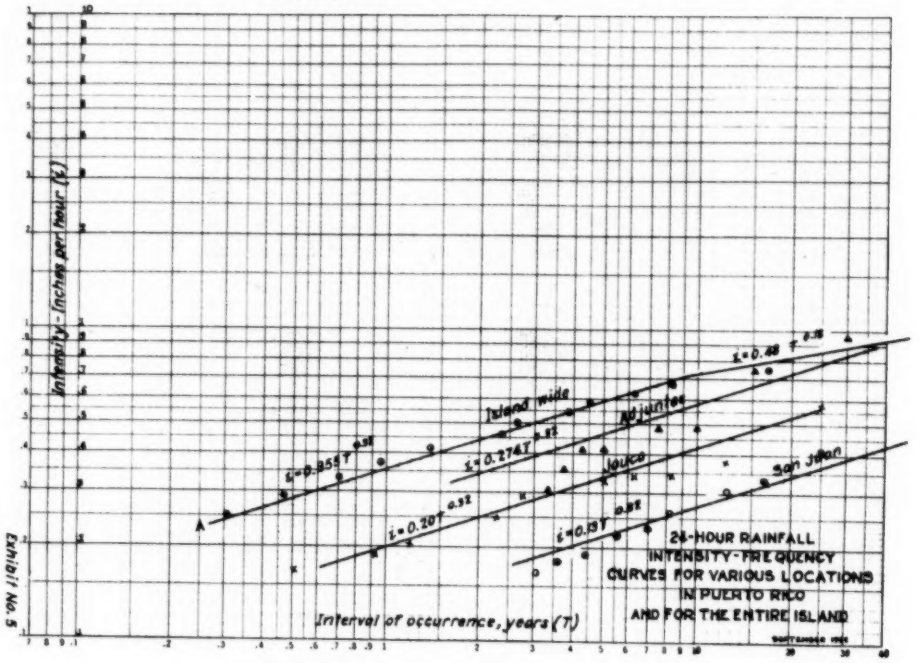
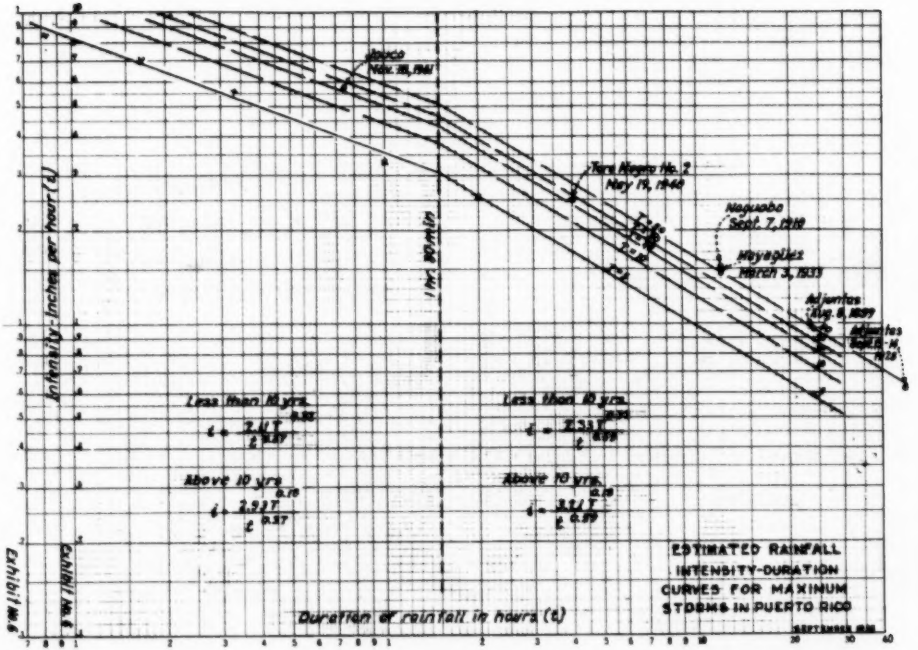

Island wide
Adjuntas
Ponce
San Juan
i=0.48 T^0.28
i=0.274T^0.28
i=0.20T^0.32
i=0.13T^0.28
Intensity - inches per hour (i)
Interval of occurrence, years (T)
24-HOUR RAINFALL
INTENSITY-FREQUENCY
CURVES FOR VARIOUS LOCATIONS
IN PUERTO RICO
AND FOR THE ENTIRE ISLAND

Exhibit No. 5


Ponce
Nov. 26, 1941
Toro Negro No. 2
May 15, 1940
Naguabo
Sept. 7, 1918
Mayagüez
March 3, 1931
Adjuntas
Aug. 8, 1899
1 Hr. 30 min.
Less than 10 yrs.
Above 10 yrs
Less than 10 yrs.
Above 10 yrs.
Intensity-Inches per hour (i)
Duration of rainfall in hours (t)
Exhibit No. 6
ESTIMATED RAINFALL INTENSITY-DURATION CURVES FOR MAXIMUM STORMS IN PUERTO RICO

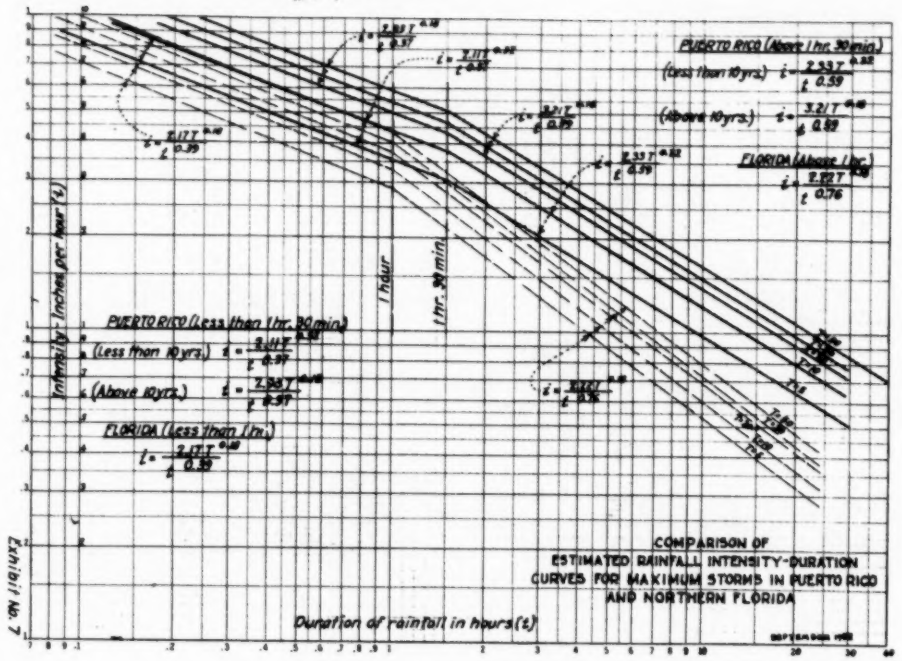
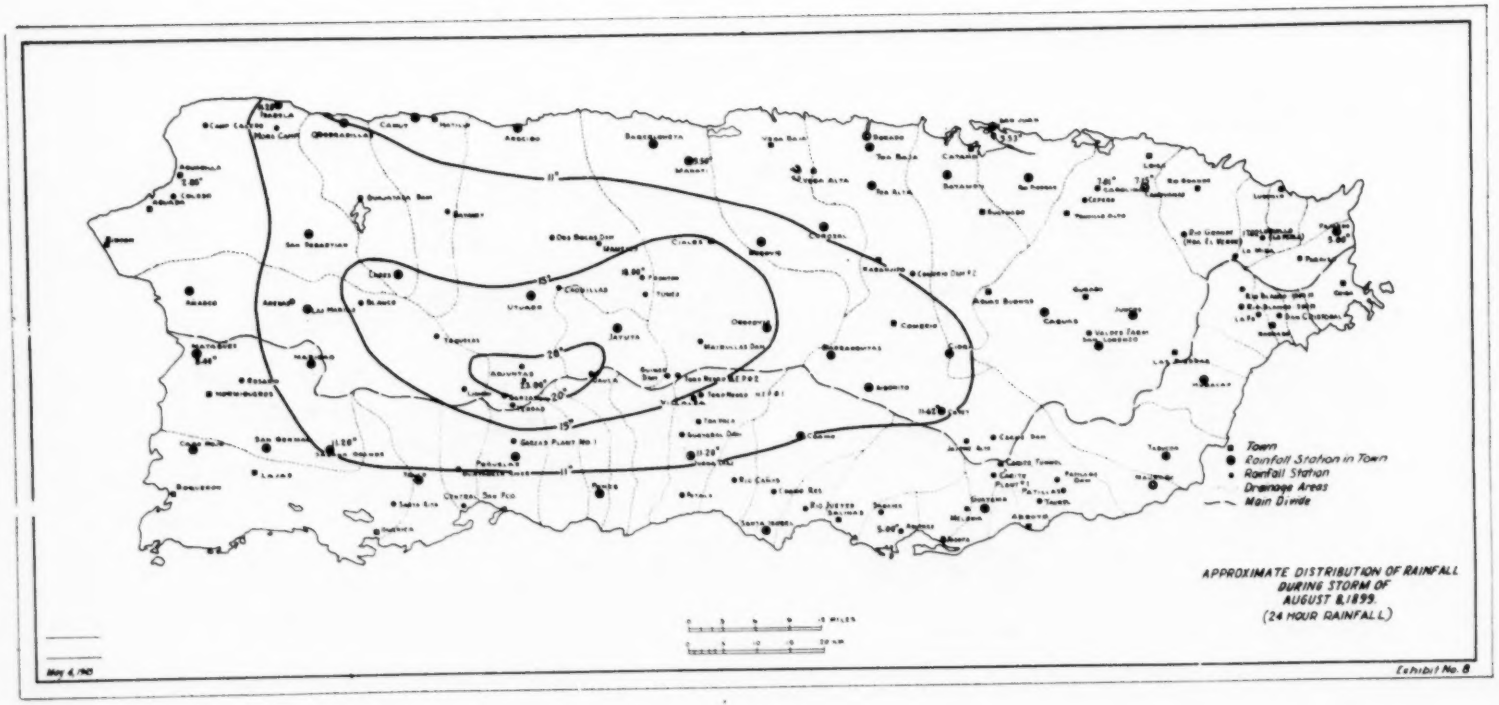
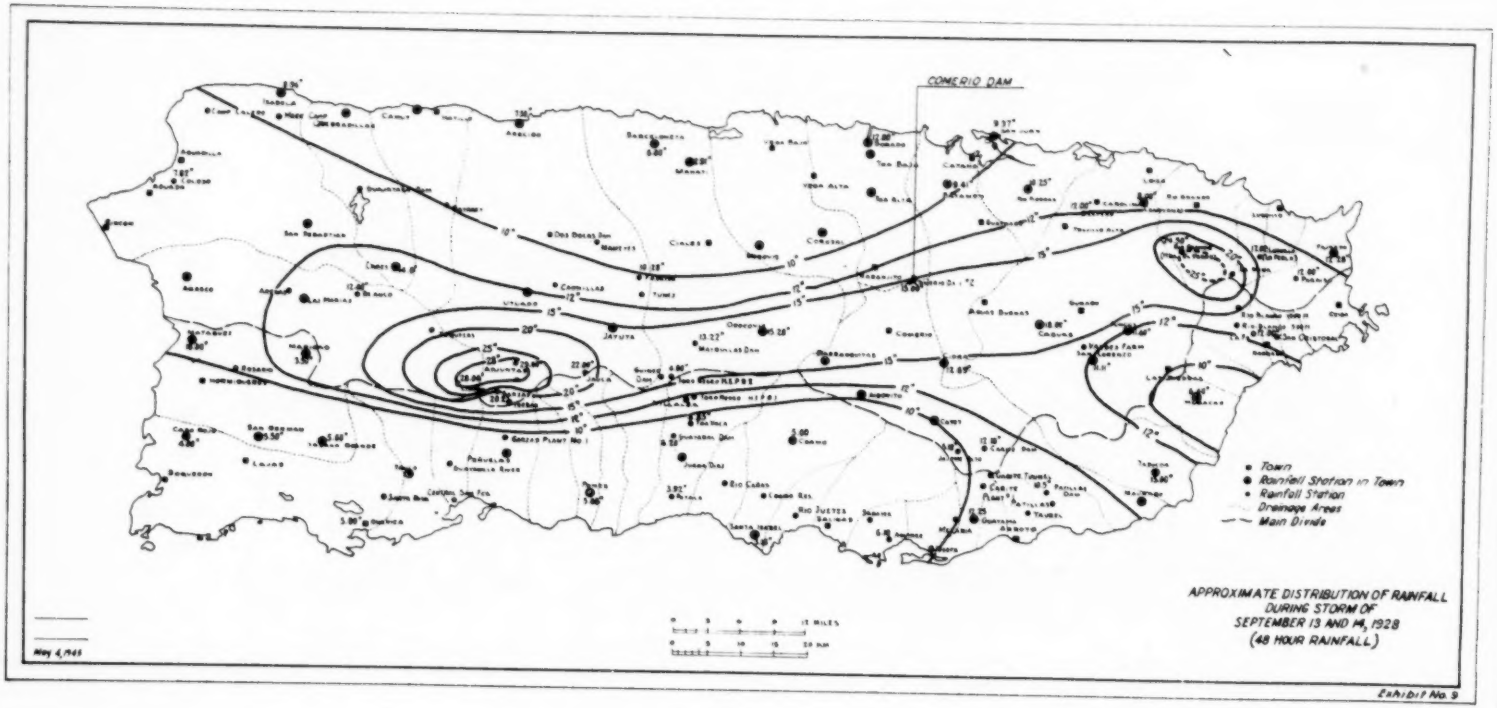
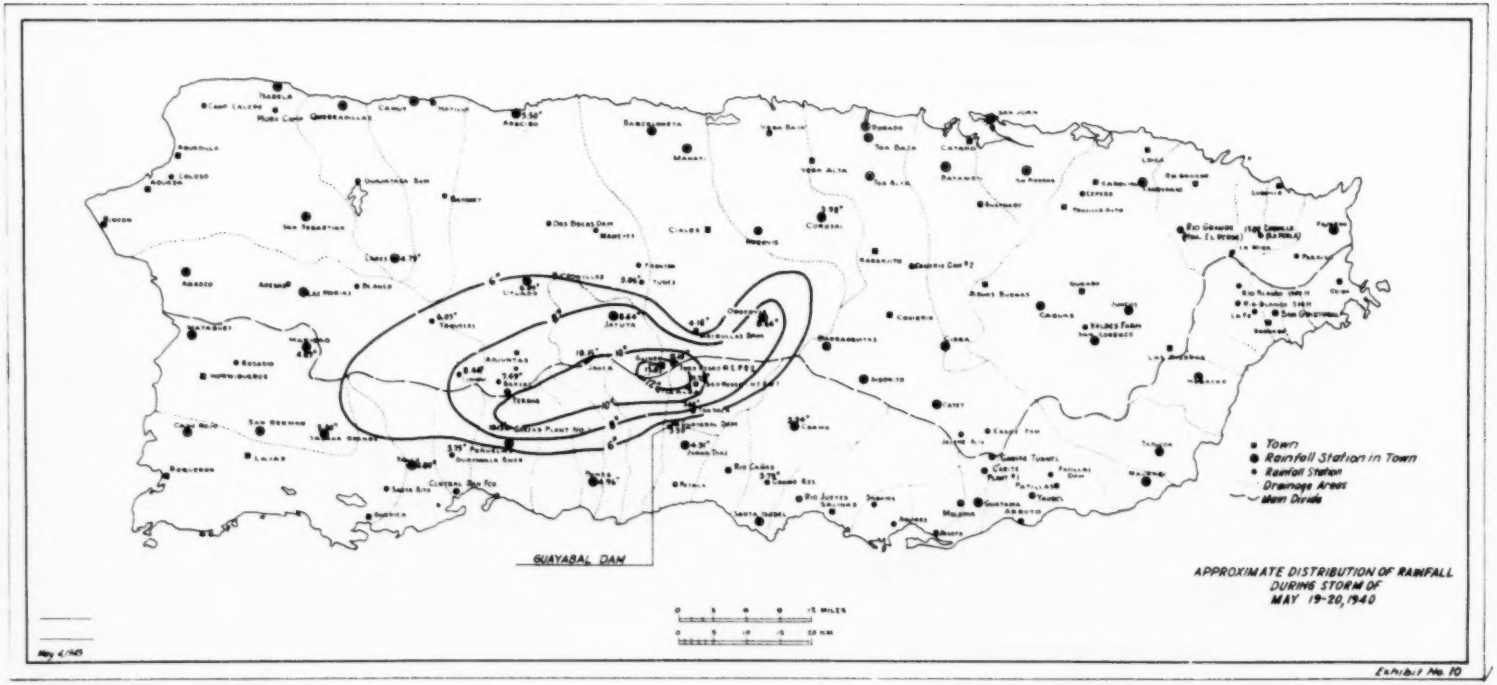
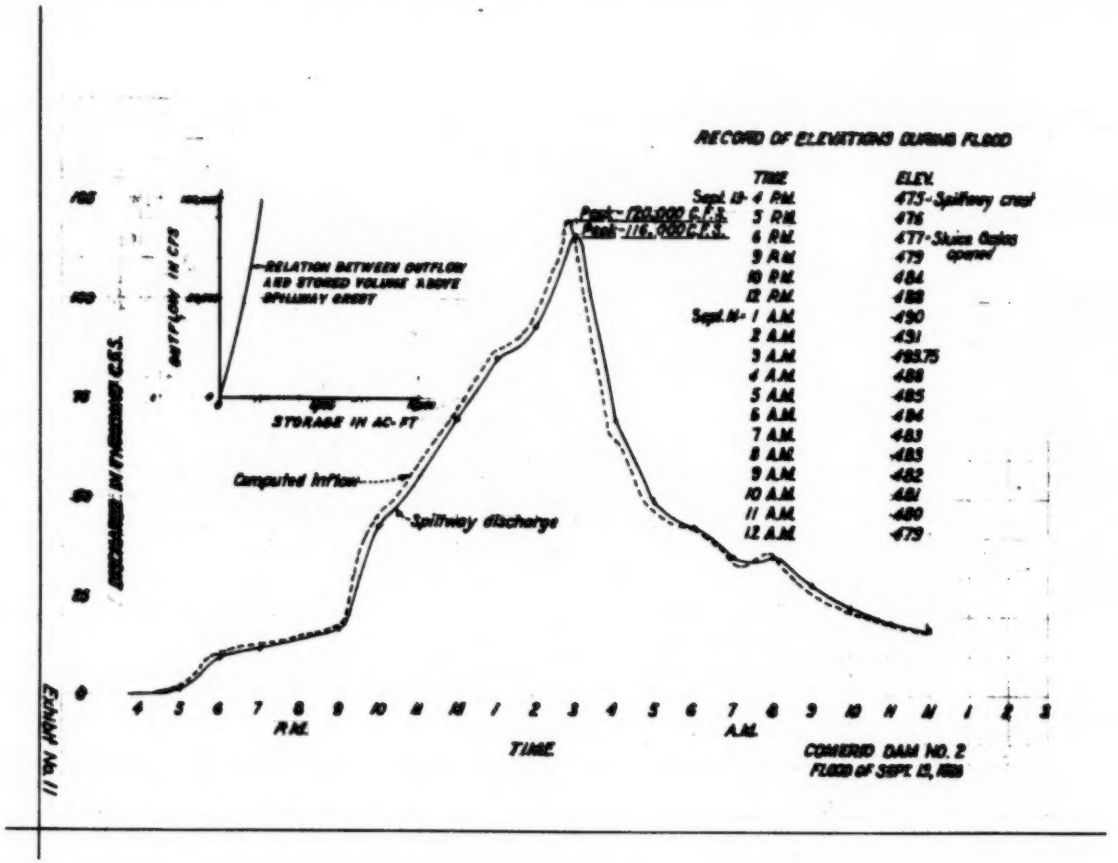

PUERTO RICO (Above 1 hr. 30 min.)
(Less than 10 yrs.) $i = \frac{2.53\,T^{0.25}}{t^{0.59}}$
(Above 10 yrs.) $i = \frac{3.2\,T^{0.28}}{t^{0.59}}$
FLORIDA (Above 1 hr.)
$i = \frac{2.82\,T^{0.28}}{t^{0.76}}$
PUERTO RICO (Less than 1 hr. 30 min.)
(Less than 10 yrs.) $i = \frac{2.11\,T^{0.28}}{t^{0.97}}$
(Above 10 yrs.) $i = \frac{2.96\,T^{0.28}}{t^{0.97}}$
FLORIDA (Less than 1 hr.)
$i = \frac{2.47\,T^{0.28}}{t^{0.89}}$
Intensity - Inches per hour (i)
1 hour
1 hr. 30 min.
Duration of rainfall in hours (t)
COMPARISON OF
ESTIMATED RAINFALL INTENSITY-DURATION
CURVES FOR MAXIMUM STORMS IN PUERTO RICO
AND NORTHERN FLORIDA

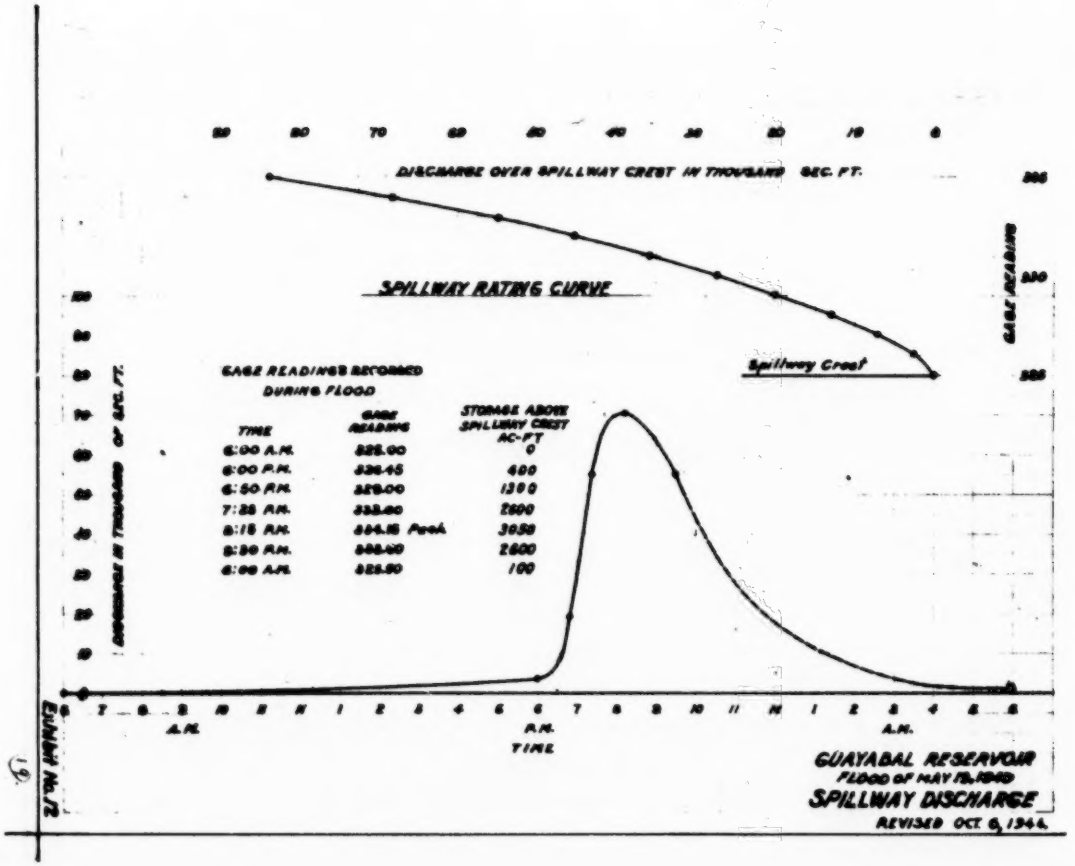
Exhibit No. 7


Town
Rainfall Station in Town
Rainfall Station
Drainage Areas
Main Divide
APPROXIMATE DISTRIBUTION OF RAINFALL
DURING STORM OF
AUGUST 8, 1899.
(24 HOUR RAINFALL)
May 4, 1965
Exhibit No. 8


COMERIO DAM
Town
Rainfall Station in Town
Rainfall Station
Drainage Areas
Main Divide
APPROXIMATE DISTRIBUTION OF RAINFALL
DURING STORM OF
SEPTEMBER 13 AND 14, 1928
(48 HOUR RAINFALL)
May 4, 1945
Exhibit No. 9


GUAYABAL DAM
Town
Rainfall Station in Town
Rainfall Station
Drainage Areas
Main Divide
APPROXIMATE DISTRIBUTION OF RAINFALL
DURING STORM OF
MAY 19-20, 1940
May 4, 1949
Exhibit No. 10


RECORD OF ELEVATIONS DURING FLOOD
TIME
ELEV.
Sept. 13- 4 P.M. 475- Spillway crest
5 P.M. 476
6 P.M. 477- Sluice Gates opened
9 P.M. 479
10 P.M. 484
12 P.M. 488
Sept. 14- 1 A.M. 490
2 A.M. 491
3 A.M. 493.75
4 A.M. 488
5 A.M. 485
6 A.M. 484
7 A.M. 483
8 A.M. 483
9 A.M. 482
10 A.M. 481
11 A.M. 480
12 A.M. 479
Peak- 120,000 C.F.S.
Peak- 116,000 C.F.S.
RELATION BETWEEN OUTFLOW AND STORED VOLUME ABOVE SPILLWAY CREST
STORAGE IN AC.-FT
Computed Inflow
Spillway discharge
DISCHARGE IN THOUSANDS C.F.S.
4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3
P.M.
A.M.
TIME
COMERIO DAM NO. 2
FLOOD OF SEPT. 13, 1928
EXHIBIT No. 11


DISCHARGE OVER SPILLWAY CREST IN THOUSAND SEC. FT.
SPILLWAY RATING CURVE
Spillway Crest
GAGE READINGS RECORDED DURING FLOOD
TIME
GAGE READING
STORAGE ABOVE SPILLWAY CREST AC-FT
6:00 A.M. 325.00 0
6:00 P.M. 326.45 400
6:50 P.M. 329.00 1300
7:25 P.M. 333.00 2600
8:15 P.M. 334.15 Peak 3050
8:30 P.M. 333.40 2600
6:00 A.M. 325.50 100
A.M.
P.M.
A.M.
TIME
GUAYABAL RESERVOIR
FLOOD OF MAY 15, 1940
SPILLWAY DISCHARGE
REVISED OCT 6, 1944.
EXHIBIT No. 12

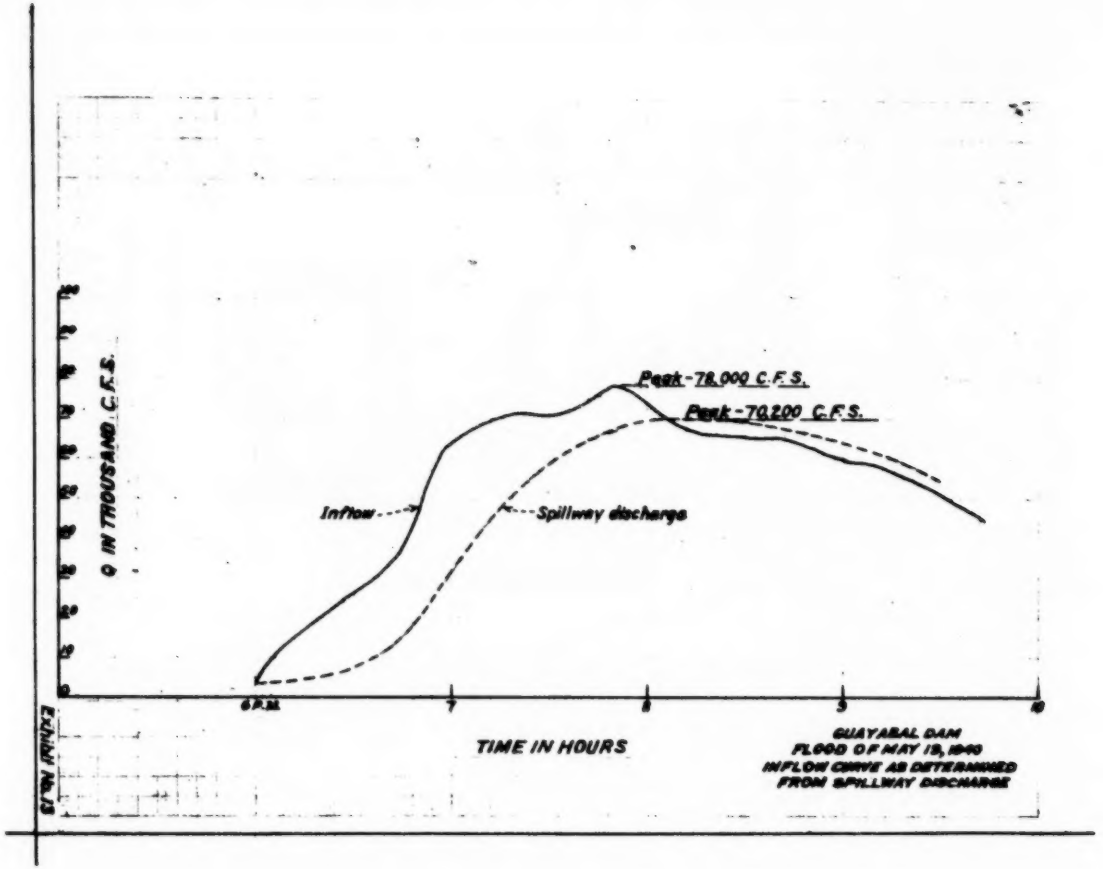
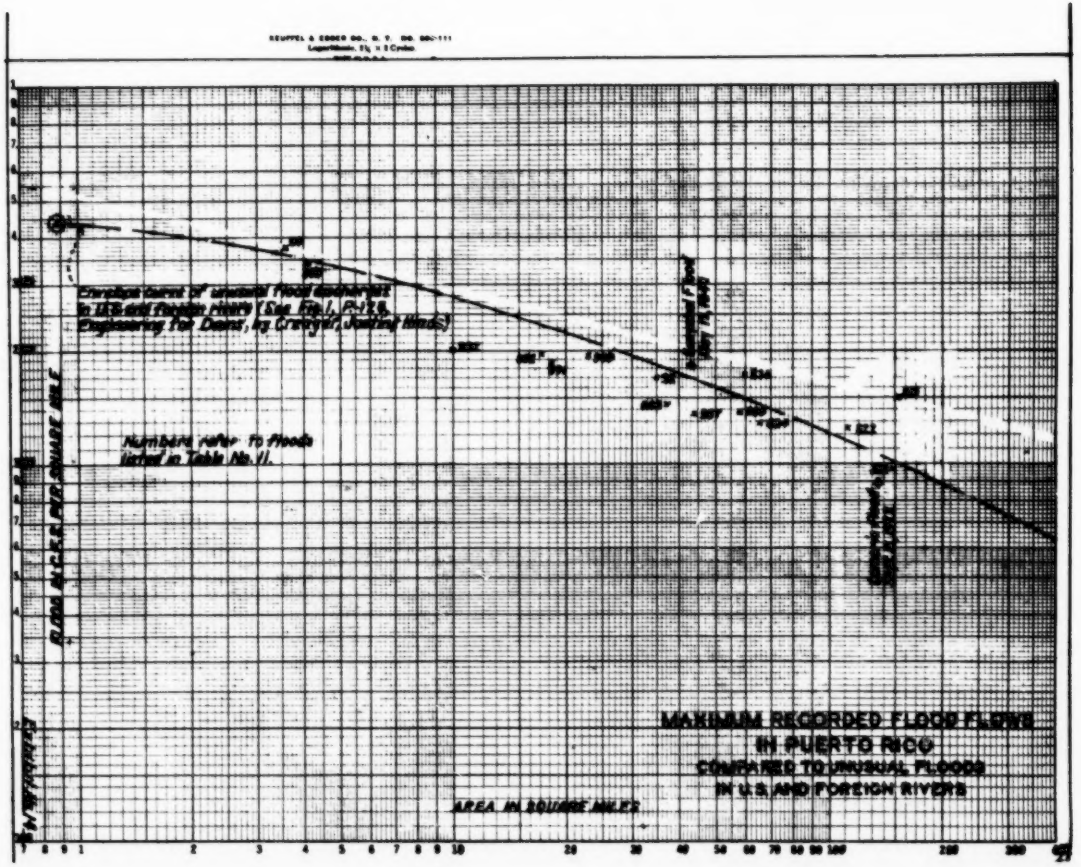


EXHIBIT NO. 13
C.F.S. IN THOUSANDS
Peak - 78,000 C.F.S.
Peak - 70,200 C.F.S.
Inflow
Spillway discharge
6 P.M.
7
8
9
10
TIME IN HOURS
GUAYABAL DAM
FLOOD OF MAY 15, 1940
INFLOW CURVE AS DETERMINED
FROM SPILLWAY DISCHARGE


Envelope Curve of observed flood discharges in U.S. and Foreign rivers (See Fig. 1, P-2.5, Engineering for Dams, by Creager, Justin and Hinds)
Numbers refer to Floods listed in Table No. VI.
FLOOD DISCHARGE IN C.F.S. PER SQUARE MILE
AREA IN SQUARE MILES
MAXIMUM RECORDED FLOOD FLOWS
IN PUERTO RICO
COMPARED TO UNUSUAL FLOODS
IN U.S. AND FOREIGN RIVERS

PROCEEDINGS-SEPARATES

VOLUME 79 (1953)

The technical papers published in the current calendar year are presented below. Technical division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering."

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MARCH: 176(SA), 177(EM), 178(HY), 179(EM), 180(HY), D-123(HY), D-126(ST), D-128(ST).

APRIL: 181(WW), 182(ST), 183(ST), 184(HY), 185(EM), 186(HY), 187(ST), 188(HY), D-135(HY), D-136(ST).

MAY: 189(HY), 190(HY), 191(CP) & (AT), 192(SM) 193(HY), D-129(PO), D-138(CP), D-145(ST).

JUNE: 194(CP) & (AT), 195(SM), 196(CP) & (AT), 197(HY), 198(ST), 199(EM), D-134(HY), D-141(HY).

JULY:[a] 200(SM),[b] 201(ST),[b] 202(EM),[b] 203(SA),[b] 204(AT),[b] 205(EM),[b] 206(ST),[b] 207(SA),[b] 208(SA),[b] 209(ST),[b] 210(SU),[b] 211(EM),[b] 212(SU),[b] 213(IR),[b] 214(HW),[b] 215(SM),[b] 216(ST),[b] 217(ST),[b] 218(ST),[b] 219(ST),[b] 220(SM),[b] 221(HW),[b] 222(SM),[b] 223(EM),[b] 224(EM),[b] 225(EM),[b] 226(CO),[b] 227(SM),[b] 228(SM),[b] 229(IR).[b]

AUGUST: 230(HY), 231(SA), 232(SA), 233(AT), 234(HW), 235(HW), 236(HW), 237(AT), 238(WW), 239(SA), 240(IR), 241(AT), 242(IR), 243(ST), 244(ST), 245(ST), 246(ST), 247(SA), 248(SA), 249(ST), 250(EM),[c] 251(ST), 252(SA), 253(AT), 254(HY), 255(AT), 256(ST), 257(SA), 258(EM), 259(WW).

SEPTEMBER: 260(AT), 261(EM), 262(SM), 263(ST), 264(WW), 265(ST), 266(ST), 267(SA), 268(CO), 269(CO), 270(CO), 271(SU), 272(SA), 273(PO), 274(HY), 275(WW), 276(HW), 277(SU), 278(SU), 279(SA), 280(IR), 281(EM), 282(SU), 283(SA), 284(SU), 285(CP), 286(EM), 287(EM), 288(SA), 289(CO).

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DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU),[e] 368(WW),[e] 369(IR), 370(AT),[e] 371(SM),[e] 372(CO),[e] 373(ST),[e] 374(EM),[e] 375(EM), 376(EM), 377(SA),[e] 378(PO).[e]

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a. Beginning with "Proceedings-Separate No. 200," published in July, 1953, the papers were printed by the photo-offset method.

b. Presented at the Miami Beach (Fla.) Convention of the Society in June, 1953.

c. Presented at the New York (N.Y.) Convention of the Society in October, 1953.

d. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.

e. Discussions, grouped by divisions.

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